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Is the P' singularity the ABFST cut?

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Abstract: The best known processes (πN, KN, NN) are analyzed phenomenologically separating, through the unitarity relation, the forward scattering amplitudes into inelastic and elastic parts. The former is found to be globally dual to the prominent Regge poles, whereas the latter corresponds to the P', probably identified as the ABFST cut.

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The ABFST multiperipheral model (1) suggests that the inelastic contributions to the unitarity equation build up the asympotic behaviour which corresponds to a Regge pole. On the other hand, the elastic part seems to be related with more complex singularities in the J-plane, i.e. cuts. Though it was shown by Mandelstam (2) that on the physical sheet of the energy the so called ABFST cut is cancelled by many particle contributions to the unitarity equation, we recall (3) that his proof is not valid in the framework of the multiperipheral boostrap model of Chew and Pignotti (4). In fact, using the CGL (5) integral equation with two input-poles, Frazer and Mehta (6) were able to construct a simplified model for the vacuum exchanges in which the amplitude consists of a Regge pole (the Pomeron) plus the ABFST cut. The pole accounts for the elastic shadow scattering due to all open inelastic channels, while the latter represents exactly the elastic contribution to the unitarity sum. If the model of (6) were to be used as a fair approximation to the real world, the cut should be associated with the P'. This picture for the vacuum singularities is in agreement with the recent suggestion that the Pomeron, more than P' , has the properties of a Regge pole (7).

Regarding the non-vacuum exchanges, it has been lately noted that at $t = 0$ the ρ Regge pole seems to be dual to that piece of the nonflip amplitude which is built, via the optical theorem, from the difference of <u>inelastic</u> cross sections for $\pi^- p$ and $\pi^+ p$ scattering (8). This is related to the scheme of "annihilation duality" (9), introduced through the study of the overlap function, where the non-dominant asymptotic part of the elastic amplitude (ρ and ω in Regge language) is assumed to arise from those inelastic channels which are present in $\bar{X}p$ scattering and absent in the Xp case ($X = \pi^+$, K^+, p), i. e. the so called "annihilation channels".

In this note, our purpose is to investigate whether a simple scheme, inspired in the previous ideas and corresponding to the duality

$$\text{inelastic part} \longleftrightarrow \text{Regge poles} ,$$

$$\text{elastic part} \longleftrightarrow \text{anything else},$$

has a phenomenological support. Except for the new concept of duality, this is not a novel idea. The same hypothesis was employed some time ago (10) in estimating the relative contribution of cuts and poles at high energy. Our main result is that the analysis of the best known processes, i.e. $\pi^{\pm}p$, $K^{\pm}p$, pp and $\bar{p}p$, in the forward direction, shows a correspondence of $\sigma^{inel}_{\bar{X}p} - \sigma^{inel}_{Xp}$ with the ρ and ω Regge poles, $\sigma^{inel}_{\bar{X}p} + \sigma^{inel}_{Xp}$ with the Pomeron, and $\sigma^{el}_{\bar{X}p} + \sigma_{c.e.} + \sigma^{el}_{Xp}$ with the P' singularity. Here $\sigma^{el(inel)}$ and $\sigma_{c.e.}$ represent total elastic (inelastic) cross sections and total charge exchange ($\bar{X}p \to X^{o} n$; $X^{o} = \pi^{o}$, $\bar{K}^{o}$, $\bar{n}$) cross sections, respectively. We shall give later a possible theoretical explanation of these results.

We start separating the unitarity relation for forward scattering into two pieces, corresponding to elastic or inelastic intermediate states

$$\text{Im } F^{(\pm)}_{el} \;(\nu,\, t = o) = \frac{q_L}{2} \;(\sigma^{el}_{\bar{X}p} + \sigma_{c.e.} \pm \sigma^{el}_{Xp}) \quad , \qquad (1)$$

$$\text{Im } F^{(\pm)}_{inel} \;(\nu,\, t = o) = \frac{q_L}{2} \;(\sigma^{inel}_{\bar{X}p} \pm \sigma^{inel}_{Xp}) \quad , \qquad (2)$$

where $\nu = \omega_L$ and q_L are respectively the lab energy and momentum of the incident X (or $\bar{X}$) particle. Clearly the complete amplitudes are $F^{(\pm)} = F^{(\pm)}_{el} + F^{(\pm)}_{inel}$.

Apart from looking for an agreement at high energy between (1) and (2), on one side, and Regge singularities on the other, we shall be interested in investigating whether this correspondence holds at low energy in average sense. For this purpose we compute, as a basis of this global duality, the finite-energy sum rule (FESR)

$$I^{(\pm)} = \int_{o}^{\nu_c} d\nu \quad \mathrm{Im}\ F^{(\pm)}_{inel} \quad (\nu,\ t = o) \quad , \qquad (3)$$

and analogously for $\mathrm{Im}F^{(+)}_{el}$. In the evaluation of the FESR we shall find the additional difficulty of the assignment of the energy singularities located below the elastic threshold. We have considered as elastic only those contributions to the unitarity sum which involve a π N, KN ($\bar{K}$N) or NN ($\bar{N}$N) intermediate state. According to this remark, the single particle poles and the energy cuts below the physical thresholds will be classified as inelastic.

We will next reproduce our results for the different processes. In all cases we compare the experimental data with the current Regge parametrizations of the <u>complete</u> amplitude

$$\mathrm{Im}\ F^{(\pm)} \quad (\nu,\ t = o) \rightarrow \ \Sigma \ \ \beta\ (t = o) \ \ \nu^{\ \alpha\ (t\ =\ o)} \quad . \qquad (4)$$

a) $\pi^{\pm}p$ Scattering

We have compared the experimental (11) $F_{el}^{(\pm)}$ and $F_{inel}^{(\pm)}$ eqs.(1) - (2), with previous Regge parameters of ρ , P and P' , obtained from fits to finite-energy sum rules and high energy data for the total amplitudes. These parameters are, e.g. from ref. (12)

$$\begin{aligned} \beta_\rho(o) &= 2.56 \text{ mb GeV}, & \alpha_\rho(0) &= .55 \;, \\ \beta_P(o) &= 21.5 \text{ mb GeV}, & \alpha_P(o) &= 1 \;, \\ \beta_{P'}(o) &= 16.8 \text{ mb GeV}, & \alpha_{P'}(o) &= .41 \;. \end{aligned} \tag{5}$$

As noted in ref. (8), from an energy $\nu \sim 4$ GeV, $\sigma_{\pi^-p}^{el} \approx \sigma_{\pi^+p}^{el}$ and $\sigma_{c.e.} \approx 0$, so that from this energy on, Im $F_{inel}^{(-)}$ corresponds to the ρ Regge pole contribution (see fig. 1a where the experimental Im $F_{inel}^{(-)}$ is confronted to the ρ contribution with parameters of eq. (5)). To see whether the experimental Im $F_{inel}^{(-)}$ is globally dual at low energies with the ρ, we have evaluated the FESR $I^{(-)}$, eq. (3). With $\nu_c = 4$ GeV, the result agrees, within 5%, with the one suggested by the ρ parameters of eq. (5). By allowing the cutoff ν_c to take several values in the intermediate energy range we have found that $I^{(-)}$ can be fitted by a single pole with only very slightly different parameters.

It must be noticed that Δ (1236) obviously does not appear in Im $F_{inel}^{(-)}$, but its exclusion is compensated in the sum rule by the reduction from total to inelastic part of the rest of the resonances.

Regarding the symmetric forward scattering amplitude, in fig. 1b we confront the experimental Im $F_{inel}^{(+)}$ with the Pomeron contribution given by parameters of eq. (5). Analogously, fig. 1c compares Im $F_{el}^{(+)}$ with the P' parametrization. One has to note that at $\nu \sim 5$ GeV the Pomeron contribution is $\sim 5\%$ less than Im $F_{inel}^{(+)}$, while at $\nu \sim 15$ GeV it is $\sim 2\%$

higher. In other words, $\sigma^{el}_{\pi^- p} \simeq \sigma^{el}_{\pi^+ p} \simeq$ constant at high energy, whereas P' decays too fast. This may indicate either that P' is a singularity more complex than a pole or that the correspondence between P and the inelastic part of the amplitude is broken at too high values of the energy. The evaluation of the symmetric inelastic sum rule $I^{(+)}$, using experimental data and including again the nucleon pole, gives as one-pole best fit for 2.5 GeV $< \nu_c <$ 4.2 GeV a Pomeron residue β_P = 21.2 mb GeV.

b) $K^{\pm}p$ Scattering

At high energies the antisymmetric amplitude receives contributions from both the ω and ρ poles, the second one being rather small. Henceforth, we group them together into the vector meson pole V, assuming degenerate trajectories. The A_2 contribution to the symmetric amplitude is expected to be of the same order of magnitude as ρ, but, since elastic cross sections on neutrons are not available, we are forced to neglect it. This is not a serious shortcoming in our approach, since the vacuum contributions are known to be much more important. In fig. 2, we confront experimental data (13) with the above mentioned Regge singularities, whose parameters were taken from previous fits with FESR or CMSR constraints. From ref. (14)

$$\beta_V = 7.7 \text{ mb GeV} \quad , \qquad \alpha_V(0) = .55 \quad , \qquad (6)$$

while for the vacuum singularities (15)

$$\begin{aligned} \beta_P &= 16.8 \text{ mb GeV} \quad , \qquad \alpha_P = 1 \quad , \\ \beta_{P'} &= 5.9 \text{ mb GeV} \quad , \qquad \alpha_{P'} = .62 \; . \end{aligned} \qquad (7)$$

Fig. 2a compares $\mathrm{Im}\, F^{(-)}_{inel}$ with the V-pole. The experimental values indicate that $\sigma^{el}_{K^- p} \simeq \sigma^{el}_{K^+ p}$ from $\nu \sim 3$ GeV, despite the very different angular structure of the differential cross sections (see D.R.O. Morrison, ref. (13)). Then, for higher energies $\mathrm{Im}\, F^{(-)}_{inel}$ is well represented by V. Figs. 2b and 2c show again a rough correspondence of $\mathrm{Im}\, F^{(+)}_{inel}$ with the Pomeron and of $\mathrm{Im}\, F^{(+)}_{el}$ with P'. The matching seems to be not so good in the last case, but we recall that the parameters of eq. (7) are strongly constrained at high energy, where the agreement is definitely better. Moreover, we cannot be confident on the quoted value for the P' intercept, because this quantity cannot be determined with precision in KN phenomenology (15,16). As in the πp case, the constancy of σ^{el} $(K^{\pm}p)$ is not compatible, within the present scheme, with P' being a simple Regge pole.

The evaluation of $I^{(-)}$, eq. (3), agrees very well with the above mentioned parametrization for V. As for $I^{(+)}$, we get a value which is $\sim$ 10% smaller than the Pomeron contribution of eq. (7) ($\nu_c \sim$ 4 GeV). Consequently the FESR for $\mathrm{Im}\, F^{(+)}_{el}$ is in excess respect to P'. We must remark that in computing the sum rules, one should include the unphysical region located below the K^-N elastic threshold. Essentially, it consists of the hyperon poles plus the $\Lambda(1405)$resonance. The last one can be evaluated according to a K-matrix parametrization (see ref. (17)). The coupling are rather uncertain, but fortunately the three singularities together contribute no more than 10% to the sum rules, so they are not essential for our conclusions.

c) $\bar{p}p$ and pp Scattering

Assuming that A_2 and ρ are negligible, we may parametrize the antisymmetric amplitude with ω and the symmetric one with the $P + P'$ system. According to ref. (18) we have

$$\beta_\omega = 40.4 \text{ mb GeV} \quad , \qquad \alpha_\omega = .22 \quad ,$$
$$\beta_P = 32.9 \text{ mb GeV} \quad , \qquad \alpha_P = 1 \quad , \tag{8}$$
$$\beta_{P'} = 35.8 \text{ mb GeV} \quad , \qquad \alpha_{P'} = .58 \quad .$$

Now, at variance with the previous cases, the experimental data (19) show that even at $\omega_L = 8$ GeV, $\sigma^{el}_{\bar{p}p} - \sigma^{el}_{pp} \simeq 2$ mb. However, this difference is only a small fraction of the total cross sections difference (10%). Then, the identification of $\text{Im}\, F^{(-)}_{inel}$ with the ω pole is accurate enough (See fig. 3a. It is noteworthy that a higher value of α_ω seems to improve the agreement). The correspondence between $\text{Im}\, F^{(+)}_{inel}$ with P and $\text{Im}\, F^{(+)}_{el}$ with P' shown in fig. 3b and fig. 3c respectively, is also quite reasonable (within a 10% discrepancy) at all energies. It is probably not too useful to calculate FESR because of the huge unphysical cut below te $\bar{p}p$ elastic threshold.

It is interesting to observe the relations among cross sections which arise from imposing the compatibility of our scheme with <u>exchange degeneracy</u>. Strong exchange degeneracy between P' and the vector meson pole thus leads to

$$\sigma^{inel}_{K^-p} - \sigma^{inel}_{K^+p} = \sigma^{el}_{K^-p} + \sigma_{K^-p \to \bar{K}^0 n} + \sigma^{el}_{K^+p} \quad , \tag{9}$$

$$\sigma^{inel}_{\bar{p}p} - \sigma^{inel}_{pp} = \sigma^{el}_{\bar{p}p} + \sigma_{\bar{p}p \to \bar{n}n} + \sigma^{el}_{pp} \quad . \tag{10}$$

Eq. (9) is experimentally well satisfied for 3 GeV $\lesssim \nu \lesssim$ 8 GeV, as expected from the previous analysis. On the contrary, the RHS of eq. (10) turns out to be about twice the LHS in the same range. This discrepancy probably comes from a breaking of exchange degeneracy in NN collisions (see e.g. ref. (20)). A similar relation involving inelastic and elastic total cross sections in πN scattering is strongly violated. This is a desirable result, since EXD is not expected to hold in that reaction.

Summarizing our phenomenological results, we have found that up to energies of the order of 8-10 GeV there is an approximate global duality between the inelastic cross sections and ω, ρ and P on one side, and between elastic cross sections and P' on the other.

A simple theoretical explanation of these facts can be found in the model of ref. (6). According to this model ω, ρ and P, which are related to the inelastic part of the unitarity sum, would be true Regge poles, whereas P' would be the effective representation of the ABFST cut. The fact that in all processes our scheme becomes less successful with increasing energy could also be understood in the framework of the multi-Regge model. First, the usual parametrizations, which treat the P' as a pole, are expected to fail asymptotically, no matter how good they are in the intermediate region. Thus, the levelling out of the elastic cross sections could be easily explained. On the other hand, the result of ref. (6) comes from the smallness of the internal Pomeron coupling in multiple particle intermediate states, i.e. the smallness of the diffractive dissociation cross section. But, as shown in ref. (21), for increasing energy the diffractive dissociation grows and may overtake the elastic cross section. From this energy on, our scheme should be taken with caution.

Our tentative assignement of Regge poles and cuts corresponds to the rescattering relative sign, at variance with the one coming from absorptive methods. It is well known that the absorptive sign is in some cases, particularly for πN charge exchange, the most appealing (22) and attempts have been made to reverse the sign of the cut in the multi-Regge model (23), showing that the theoretical basis is far from firm. However, Henzi (9) has noticed that absorptive cuts are generated by reproducing with simple forms the overlap function. Since the latter is determined essentially according to our recipe, the absorptive corrections seem to be already included in our duality scheme for the Regge poles. Regarding the rescattering cut associated with P', we adhere to the opinion of Frazer and Mehta (6) that its origin is a more subtle phenomenon.

The form of global duality: inelastic part vs. absorbed Regge poles and elastic part vs. P' is an alternative to the usual Harari's duality: resonances vs. Regge poles, background vs. Pomeron. None of them is experimentally exact but both are approximatively proved in some intermediate region of energy.

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REFERENCES

(1) L. Bertocchi, S. Fubini and M. Tonin, Nuovo Cimento 25 (1962) 626; D. Amati, A. Stanghellini and S. Fubini, Nuovo Cimento 26 (1962) 896.

(2) S. Mandelstam, Nuovo Cimento 30 (1963) 1127.

(3) W.R. Frazer, Proceedings of the 14th Int. Conf. on High Energy Physics, CERN (Geneva 1968) p. 420.

(4) G.F. Chew and A. Pignotti, Phys. Rev. 176 (1968) 2112.

(5) G.F. Chew, F.E. Low and M.L. Goldberger, Phys. Rev. Letters 22 (1969) 208.

(6) W.R. Frazer and C.H. Mehta, Phys. Rev. Letters 23 (1969) 258; see also: G.F. Chew and W.R. Frazer, Phys. Rev. 181 (1969) 1914.

(7) G. Hohler, F. Steiner and R. Strauss, Zeit. Phys. 233 (1970) 430; P. Achuthan, H.G. Schaile and F. Steiner, Nucl. Phys. B 24 (1970) 398.

(8) G. Hohler, H.P. Jacob and R. Strauss, Elastic Unitarity in πN CEX Scattering, Karlsruhe Preprint (1970).

(9) R. Henzi, Nuovo Cimento 52 A (1967) 772, and 57 A (1968) 301; R. Henzi, A. Kotánski, D. Morgan and L. Van Hove, Nucl. Phys. B 16 (1970) 1.

(10) P.G.O. Freund and P.J. O'Donovan, Phys. Rev. Letters 20 (1968) 1329.

(11) G. Giacomelli, P. Pini and S. Stagni, CERN-HERA Compilation 69-1 (1969).

(12) A. Della Selva, L. Masperi and R. Odorico, Nuovo Cimento 54 A (1968) 979, and 55 A (1968) 602.

(13) C. Bricman et al., Phys. Letters 31 B (1970) 148;
D.R.O. Morrison, Lund report, CERN /D. Ph. II/PHYS 69-28 (1969);
R. Armenteros et al., Nucl. Phys. B 8 (1968) 233;
B. Martin et al., Phys. Rev. 183 (1969) 1345;
Particle Data Group, A compilation of K^+N reactions, UCRL-20000 K^+N (1969);
M. Watson et al., Phys. Rev. 131 (1963) 2248;
P. Bastien et al., Phys. Rev. Letters 10 (1963) 188;
D. Bugg et al., Phys. Rev. 168 (1968) 1466;
R.L. Cool et al., Phys. Rev. D 1 (1970) 1887;
R.J. Abrams et al., Phys. Rev. D 1 (1970) 1917;
A. Diddens et al., Phys. Rev. 132 (1963) 2721;
W. Baker et al., Phys. Rev. 129 (1963) 2285;
W. Galbraith et al., Phys. Rev. 138 B (1965) 913;
R. Armenteros et al., Nucl. Phys. B 21 (1970) 15.

(14) E. Ferrari and G. Violini, Nuovo Cimento Lettere 4 (1970) 483.

(15) C. Ferro Fontán, M. Lusignoli, R. Odorico, M. Restignoli and G. Violini, Nuovo Cimento 57 A (1968) 442.

(16) M. Restignoli and G. Violini, Phys. Letters 31 B (1970) 533.

(17) G. Ebel, H. Pilkuhn and F. Steiner, Nucl. Phys. B 17 (1970) 1.

(18) N.H. Buttimore, Phys. Rev. 170 (1968) 1466.

(19) Experimental Data on Hadron Interactions in GeV Region, Suppl. Progress Theor. Phys., Extra Number (1967).

(20) J. Mandula, J. Weyers and G. Zweig, Phys. Rev. Letters 23 (1969) 266.

(21) G.F. Chew, T. Rogers and D.R. Snider, Phys. Rev. D 2 (1970) 765.

(22) J. Finkelstein and M. Jacob, Nuovo Cimento 56 A (1968) 681.

(23) L. Caneschi, Phys. Rev. Letters 23 (1969) 254.

FIGURE CAPTIONS

Fig. 1 - Comparison of $\pi^{\pm} p$ amplitudes for $t = o$ with Regge poles. The solid curves represent the experimental data (ref. 11)), the dashed lines are the Regge contributions (eq. 5)).

a) $\mathrm{Im}\, F^{(-)}_{inel} = \frac{1}{2}\, q_L \left(\sigma^{inel}_{\pi^- p} - \sigma^{inel}_{\pi^+ p}\right)$ vs. ρ pole;

b) $\mathrm{Im}\, F^{(+)}_{inel} = \frac{1}{2}\, q_L \left(\sigma^{inel}_{\pi^- p} + \sigma^{inel}_{\pi^+ p}\right)$ vs. P ;

c) $\mathrm{Im}\, F^{(+)}_{el} = \frac{1}{2}\, q_L \left(\sigma^{el}_{\pi^- p} + \sigma_{c.e.} + \sigma^{el}_{\pi^+ p}\right)$ vs. P' .

Fig. 2 - Comparison of $K^{\pm} p$ amplitudes for $t = o$ with Regge poles. Solid curves: experimental data (ref. (13)); dashed lines: Regge contributions (eqs. (6) and (7)).

a) $\mathrm{Im}\, F^{(-)}_{inel}$ vs. vector meson pole V;

b) $\mathrm{Im}\, F^{(+)}_{inel}$ vs. P;

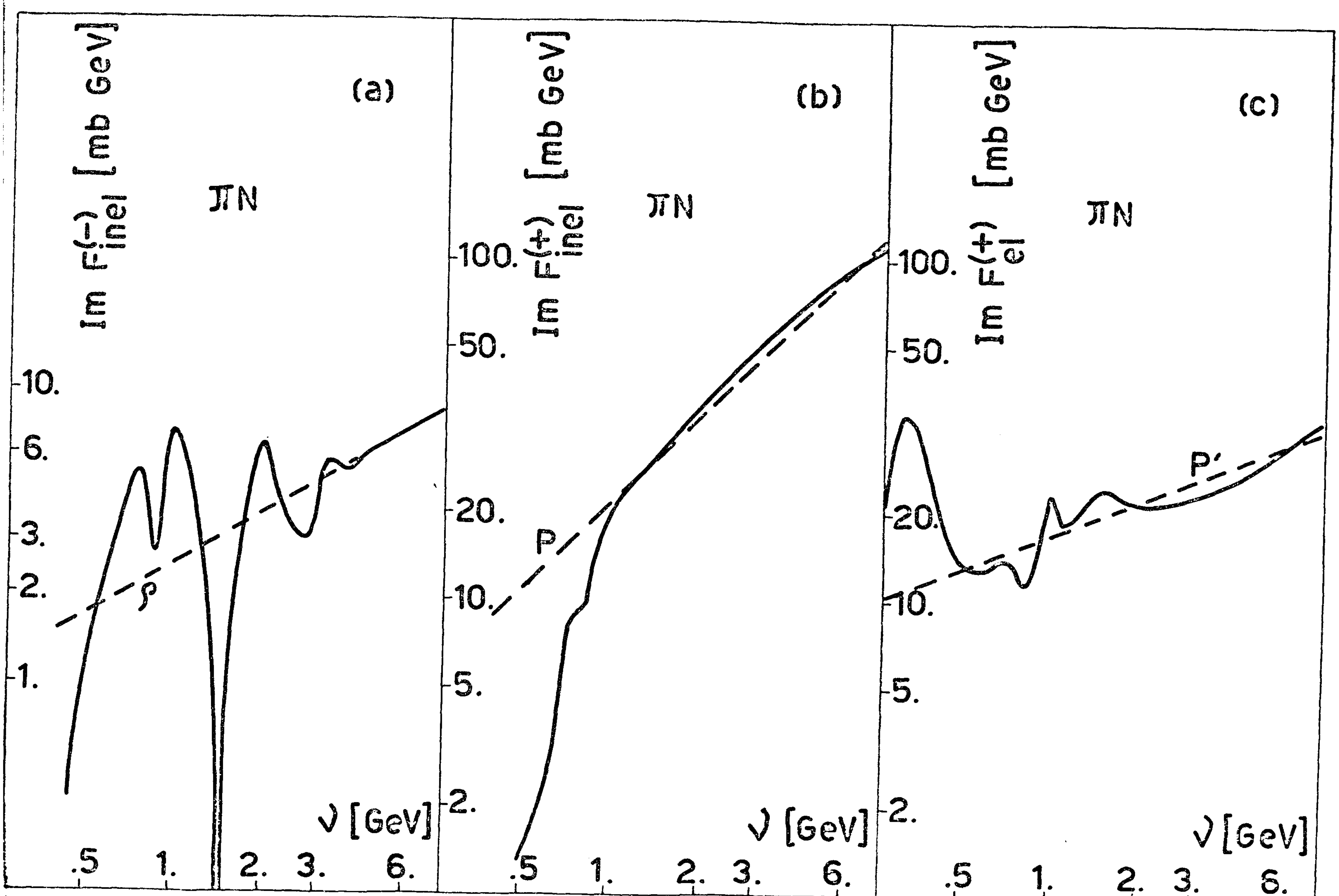
c) $\mathrm{Im}\, F^{(+)}_{el}$ vs. P' .

Fig. 3 - Comparison of $\bar{p}p$ and pp amplitudes for $t = o$ with Regge poles. Solids curves: experimental data (ref. (19)); dashed lines: Regge contributions (eqs. (8)).

a) $\mathrm{Im}\, F^{(-)}_{inel}$ vs. ω ;

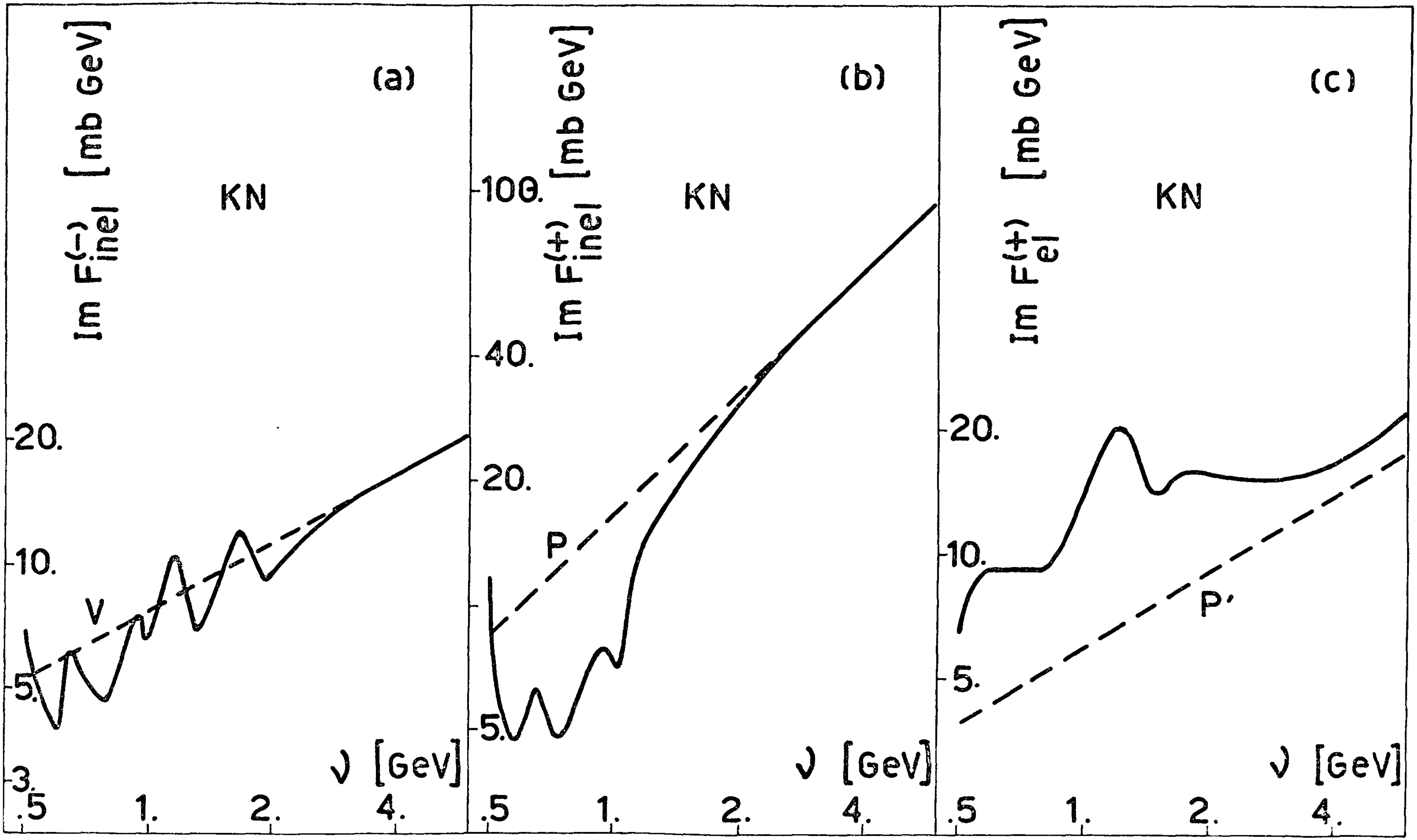
b) $\mathrm{Im}\, F^{(+)}_{inel}$ vs. P ;

c) $\mathrm{Im}\, F^{(+)}_{el}$ vs. P' .



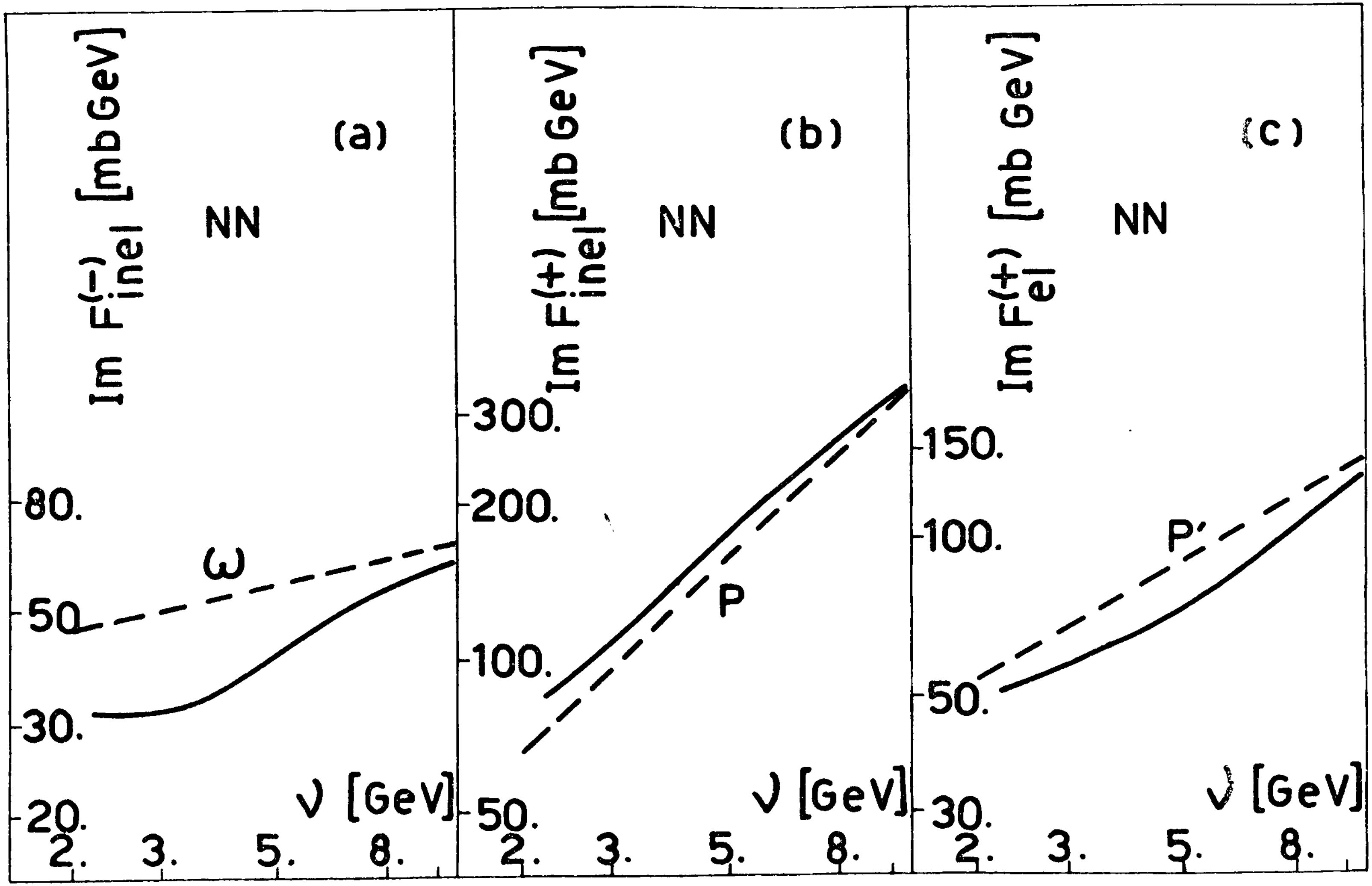
Im $F^{(-)}_{inel}$ [mb GeV]
(a)
πN
10.
6.
3.
2.
1.
ρ
.5
1.
2.
3.
6.
ν [GeV]
Im $F^{(+)}_{inel}$ [mb GeV]
(b)
πN
100.
50.
20.
10.
5.
2.
P
.5
1.
2.
3.
6.
ν [GeV]
Im $F^{(+)}_{el}$ [mb GeV]
(c)
πN
100.
50.
20.
10.
5.
2.
P'
.5
1.
2.
3.
6.
ν [GeV]

Figure 1



(a)
KN
Im $F^{(-)}_{inel}$ [mb GeV]
V
20.
10.
5.
3.
.5
1.
2.
4.
ν [GeV]
(b)
KN
Im $F^{(+)}_{inel}$ [mb GeV]
P
100.
40.
20.
5.
.5
1.
2.
4.
ν [GeV]
(c)
KN
Im $F^{(+)}_{el}$ [mb GeV]
P′
20.
10.
5.
.5
1.
2.
4.
ν [GeV]

Figure 2



(a)
NN
Im $F^{(-)}_{inel}$ [mb GeV]
ω
80.
50.
30.
20.
2.
3.
5.
8.
ν [GeV]
(b)
NN
Im $F^{(+)}_{inel}$ [mb GeV]
P
300.
200.
100.
50.
2.
3.
5.
8.
ν [GeV]
(c)
NN
Im $F^{(+)}_{el}$ [mb GeV]
P'
150.
100.
50.
30.
2.
3.
5.
8.
ν [GeV]

Figure 3